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(54) **BODY-MOUNTABLE DEVICE WITH ANTENNA FORMING EXTERNAL SIDEWALL**

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H04W 88/06 (2009.01)
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See application file for complete search history.

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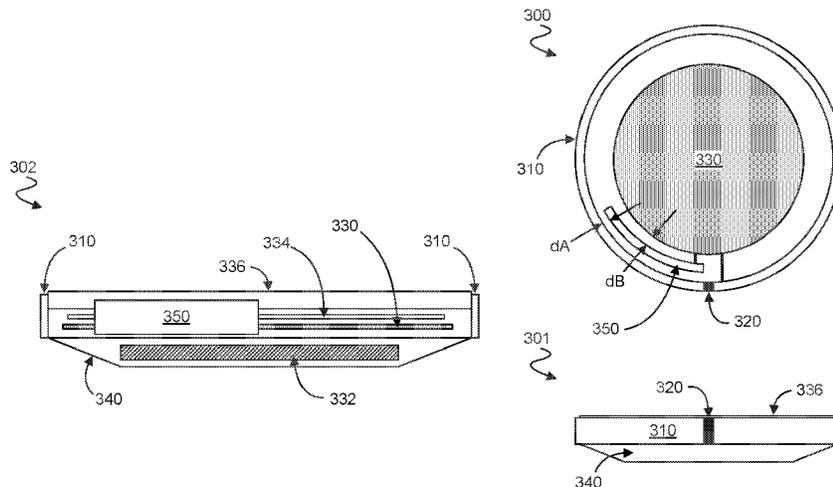
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Primary Examiner — Wen W Huang

(57) **ABSTRACT**

Techniques and mechanisms to provide wireless communication with a body-mountable device comprising a single-loop antenna. In an embodiment, distal ends of the single-loop antenna are disposed on opposite sides of a slit structure, wherein the single-loop antenna extends around a controller configured to provide any of multiple modes of high-frequency communication with the single-loop antenna. Different operational modes each provide for operation of the single-loop antenna with both a proximity-coupled feed structure and a first contact at or near a distal end of the single-loop antenna. In another embodiment, the single-loop antenna forms a hole or a recess structure which is aligned with a sensor or an input/output (I/O) mechanism of the body-mountable device.

20 Claims, 7 Drawing Sheets



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H01Q 7/00 (2006.01)
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H01Q 5/30 (2015.01)
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- (52) **U.S. Cl.**
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(2013.01); *H04M 1/04* (2013.01); *H04W*
88/06 (2013.01)

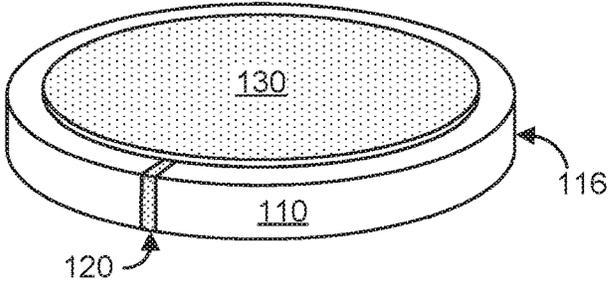
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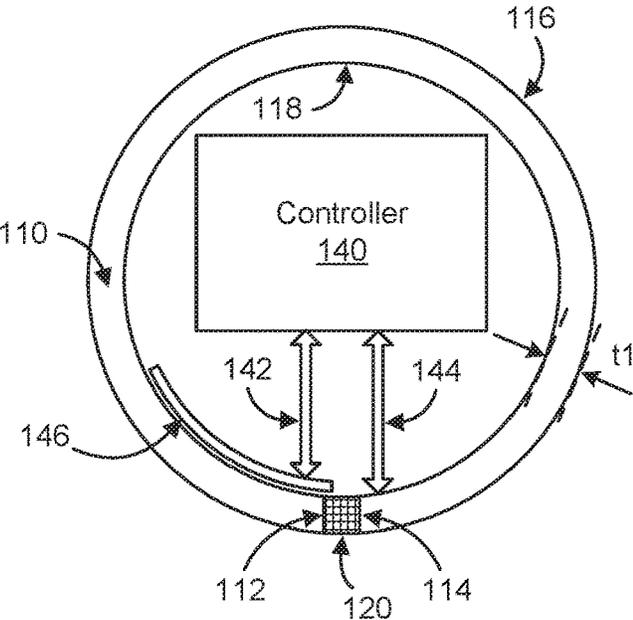
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100



101



102

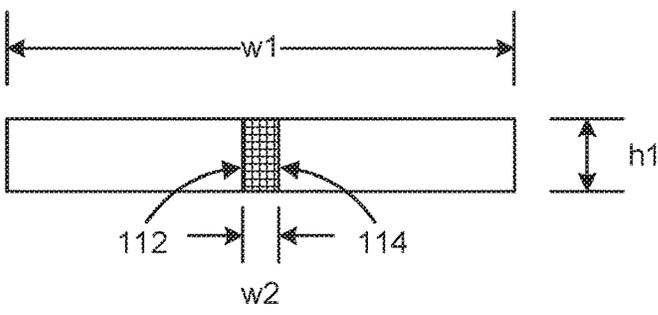


FIG. 1A

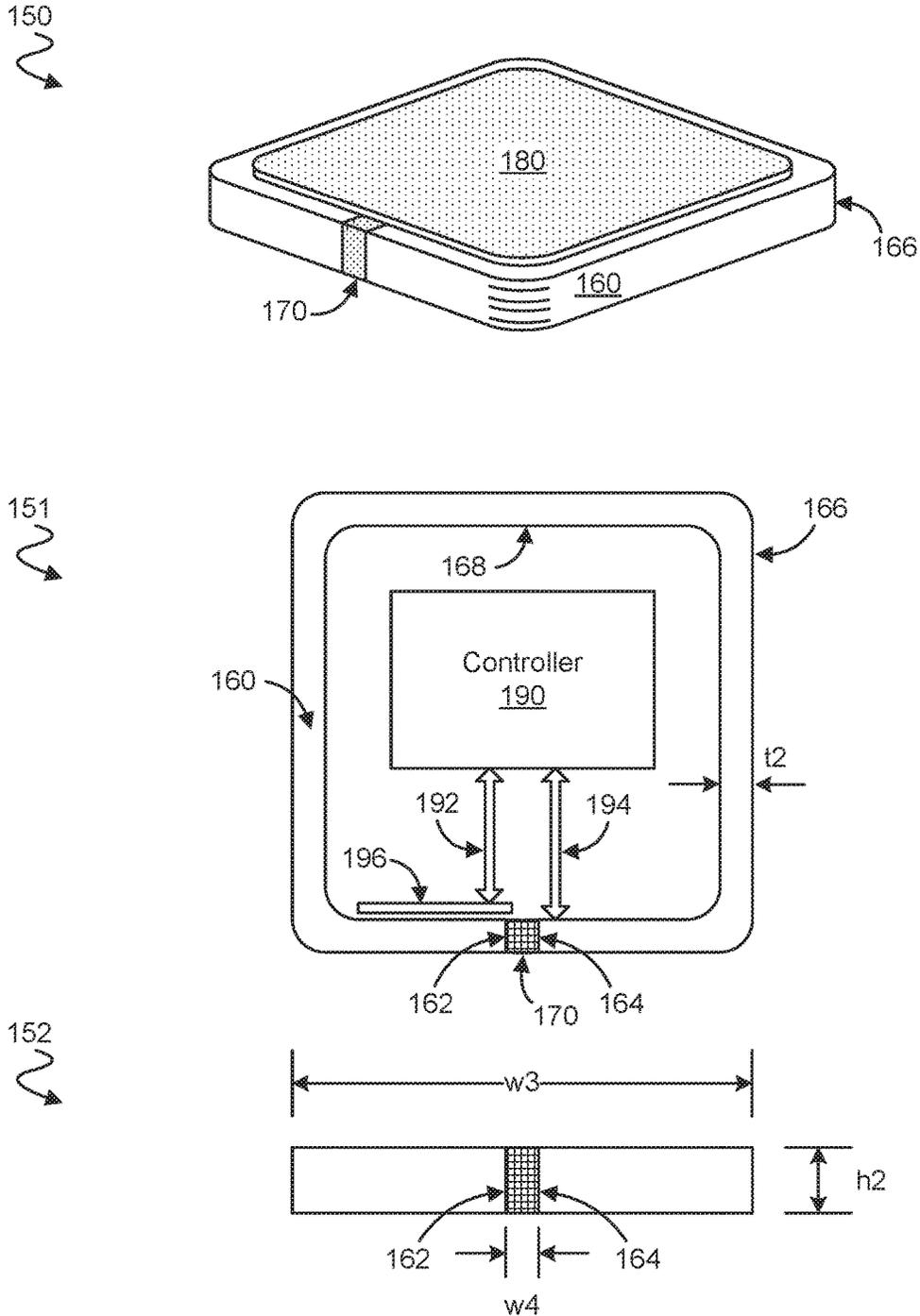


FIG. 1B

200
↘

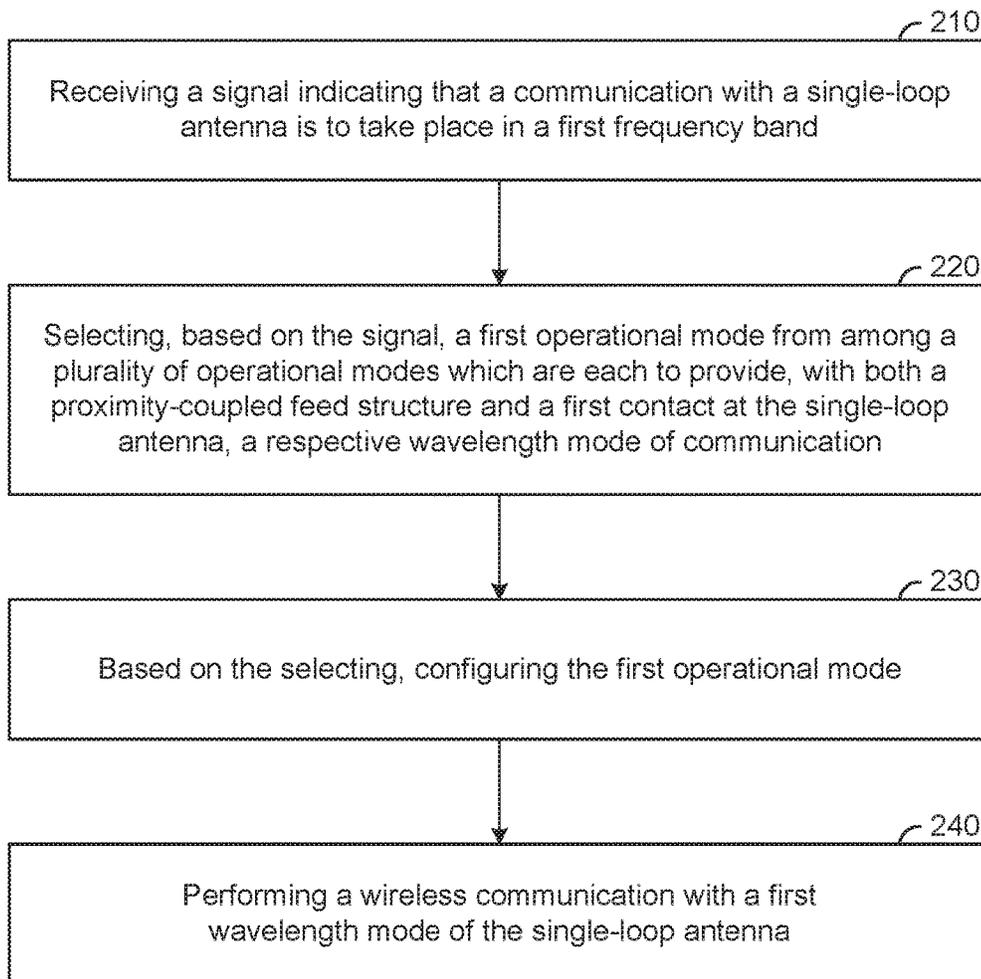


FIG. 2

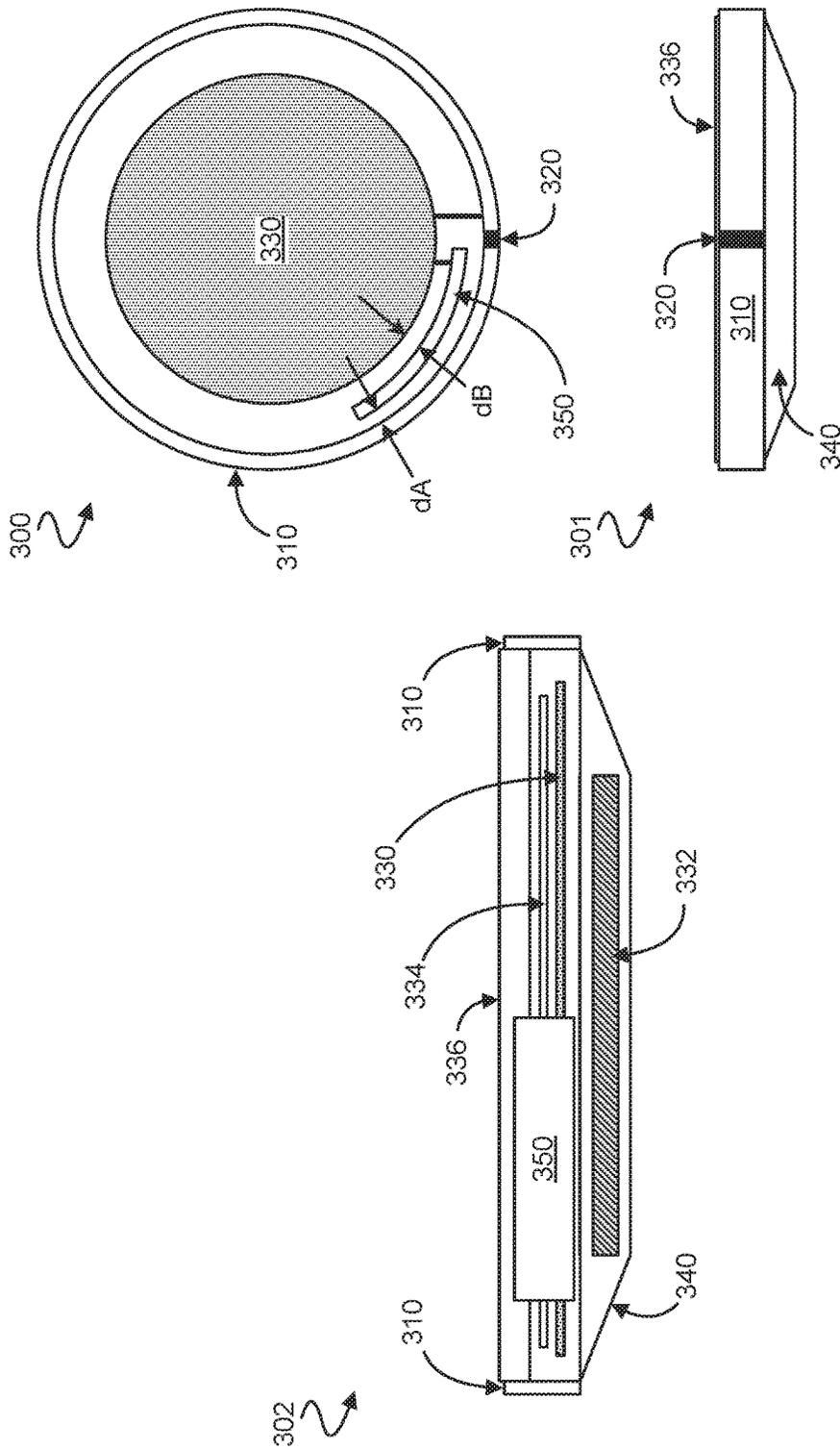


FIG. 3

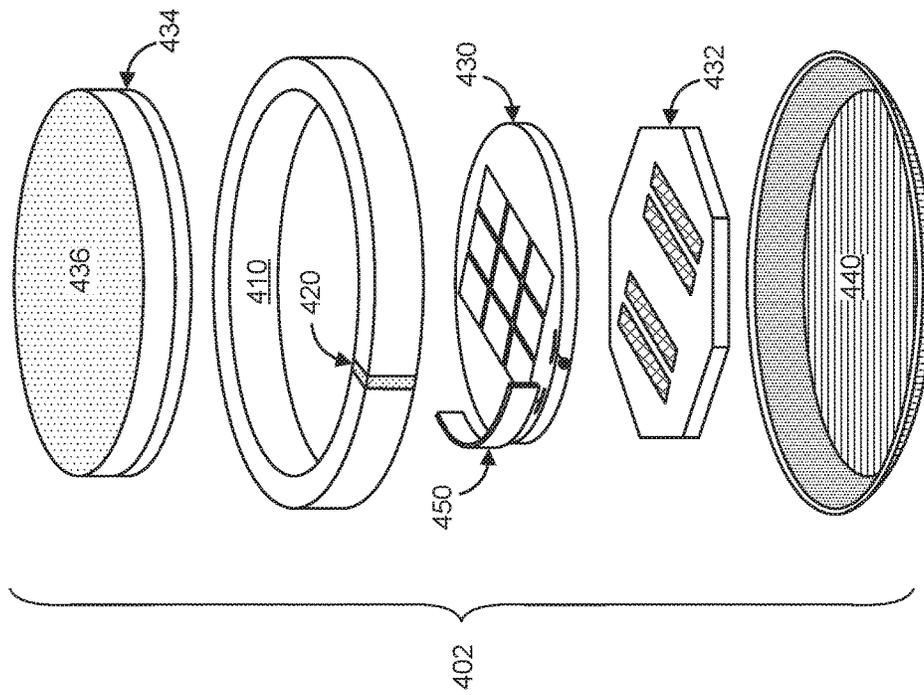
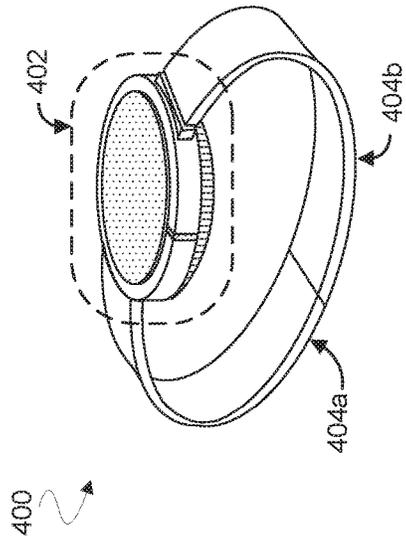


FIG. 4

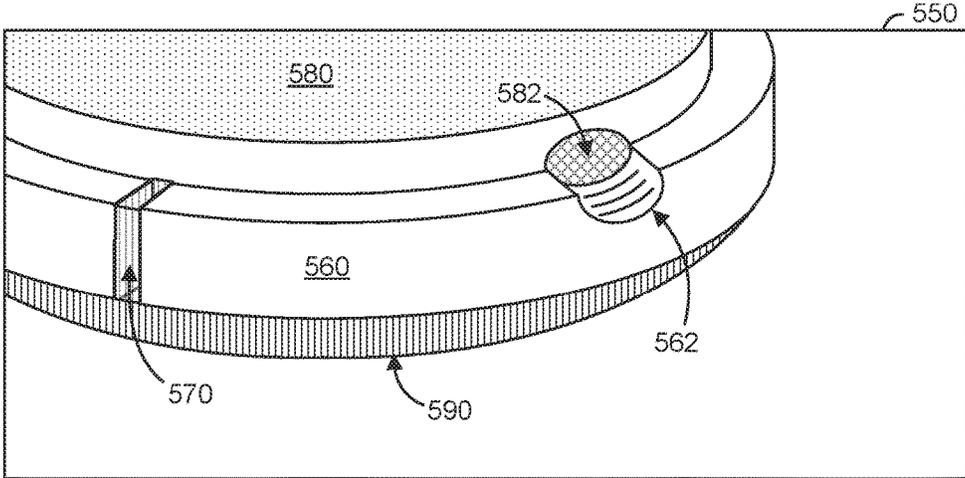
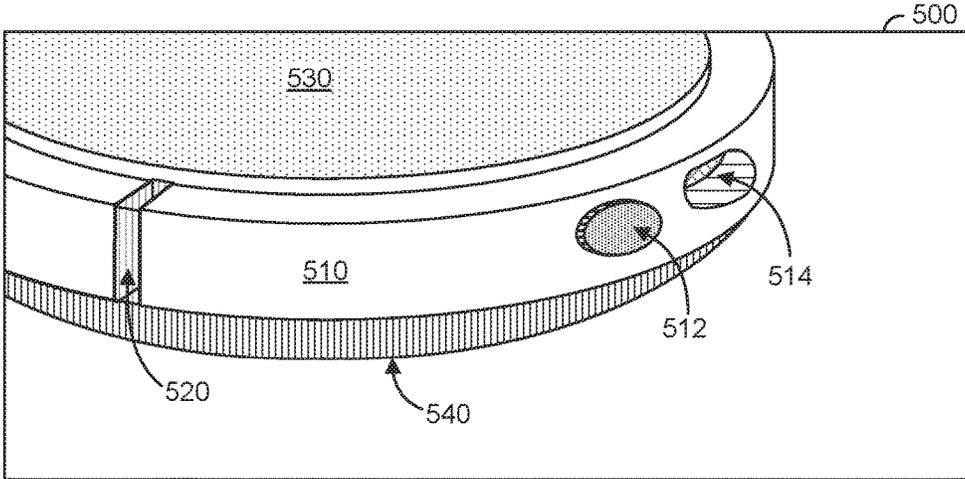


FIG. 5

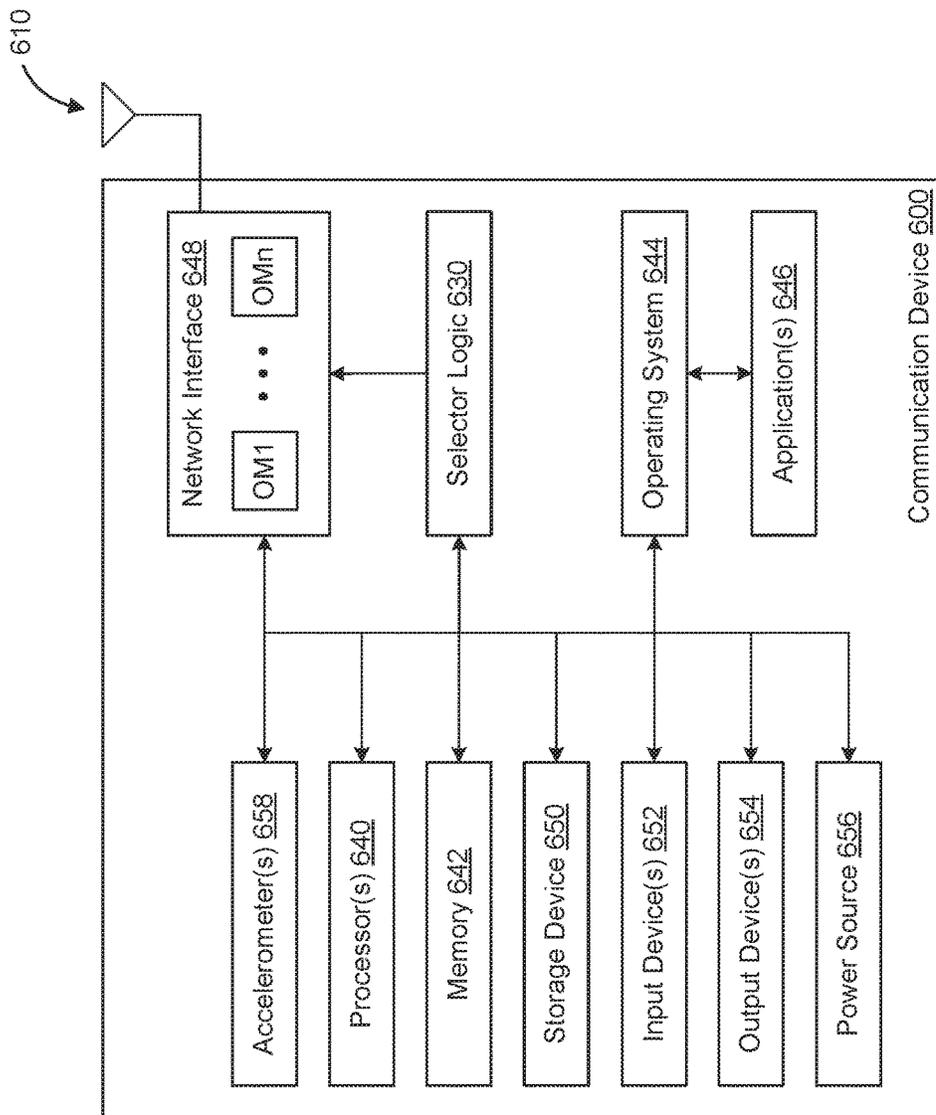


FIG. 6

BODY-MOUNTABLE DEVICE WITH ANTENNA FORMING EXTERNAL SIDEWALL

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation application of U.S. patent application Ser. No. 15/453,770, entitled “BODY-MOUNTABLE DEVICE TO PROVIDE RADIO-FREQUENCY WIRELESS COMMUNICATION” and filed on Mar. 8, 2017, the entirety of which is incorporated by reference herein.

BACKGROUND

1. Technical Field

Embodiments of the present invention relate generally to mobile devices and more particularly, but not exclusively, to antenna structures of a body-mountable communication device.

2. Background Art

With an ever-increasing demand for wireless communication access, various portable devices—that traditionally are not constructed as communicating devices—are being designed with integrated wireless communication capability. To date, small form factor devices have been limited to re-designs that provide only somewhat limited wireless network functionality. In one typical example, a conventional body area network includes both a smart phone and a smaller mobile device which is designed to participate in near-field communication with the smart phone. The near-field communication is relatively low frequency, where the smart phone functions as access point to provide higher-bandwidth access to a larger wireless network on behalf of the other mobile device.

As mobile devices continue to grow in number, functionality and variety, there is expected to be an increasing premium placed on solutions for small form factor mobile devices to operate in systems which support high-frequency wireless communication.

BRIEF DESCRIPTION OF THE DRAWINGS

The various embodiments of the present invention are illustrated by way of example, and not by way of limitation, in the figures of the accompanying drawings and in which:

FIGS. 1A, 1B show respective body-mountable devices each to provide wireless communication according to a corresponding embodiment.

FIG. 2 shows a method to operate a body-mountable device according to an embodiment.

FIG. 3 shows a body-mountable device to perform communication with a single-loop antenna according to an embodiment.

FIG. 4 shows a system to provide high-frequency wireless communication according to an embodiment.

FIG. 5 shows a body-mountable device to perform communication with a single-loop antenna according to an embodiment.

FIG. 6 is a high-level functional block diagram showing features of a communication device according to an embodiment.

DETAILED DESCRIPTION

Embodiments described herein variously provide wireless communication with a body-mountable device comprising an antenna which forms a single loop structure (for brevity, a “single-loop antenna”). In an embodiment, the single-loop antenna extends around a region in which is disposed circuitry of the body-mountable device, where such circuitry is configured to provide any of multiple modes of high-frequency communication using the single-loop antenna. Such high-frequency communication may be, for example, be according to or otherwise compatible with a long-term evolution (LTE) standard such as the LTE standard finalized in December 2008 by the 3rd Generation Partnership Project (3GPP) or the LTE Advanced standard released in March 2011 by 3GPP.

FIG. 1A illustrates features of a body-mountable communication device **100** to provide wireless communication according to an embodiment. Body-mountable communication device **100** is one example of an embodiment wherein a mobile device is configured to be worn directly or indirectly on a body of a user. An exterior sidewall of the mobile device may be formed at least in part by a loop antenna that facilitates radio frequency communication such as that according to a LTE standard. Unless otherwise indicated, ‘radio frequency communication’ refers herein to communication which is at a frequency equal to or more than 100 megahertz (MHz). Some embodiments support a wide band of LTE (or other) radio frequency communication modes—e.g., wherein a difference between a first frequency of a first communication mode and a second frequency of a second communication mode is 1000 MHz or more—e.g., wherein the difference is 1500 MHz or more and, in some embodiments, 2000 MHz or more.

In the illustrative embodiment shown, body-mountable communication device **100** includes a single-loop antenna **110** extending around a region **130** in which is disposed circuitry to facilitate wireless communication using single-loop antenna **110**. Such circuitry may include transmitter logic and/or receiver logic—e.g., where other circuitry of communication device **100** provides for input and/or output (I/O) which is based on (or which determines) such communication.

Single-loop antenna **110** may structurally define at least in part (e.g., may extend almost entirely around) a periphery of region **130**—e.g., wherein an exterior side **116** of the antenna **110** (opposite an interior side **118**) forms an exterior sidewall structure of device **100**. Such a sidewall structure may conform to a circle, ellipse, rectangle (e.g., a square) or any of a variety of other shapes. In some embodiments, antenna **110** further forms any of a variety of bevel structures (not shown) adjoining side **116**.

As variously shown in the top view **101** and side view **102** of communication device **100**, single-loop antenna **110** may have a height **h1** and a width **w1**, wherein a given section along a length of single-loop antenna **110** has a thickness **t1**. By way of illustration and not limitation, an average of height **h1** may be in a range of 3 mm to 8 mm (e.g., in a range of 4 mm to 6 mm)—e.g., where an average of width **w1** is in a range of 50 mm to 80 mm (e.g., in a range of 55 mm to 65 mm) and/or an average of thickness **t1** is in a range of 0.5 mm to 1.5 mm (e.g., in a range of 0.8 mm to 1.2 mm). Alternatively or in addition, an overall length along antenna **110** between distal ends **112**, **114** thereof (the overall length measured around a periphery of region **130**) may be less than 250 mm—e.g., in a range of 100 mm to 250 mm. However,

such dimensions of antenna 110 are merely illustrative, and may vary in different embodiments according to implementation-specific details.

Single-loop antenna 110 may facilitate functionality to participate in wireless communication to and/or from communication device 100. For example, single-loop antenna 110 may comprise stainless steel, aluminum, magnesium and/or any of a variety of other metals adapted from conventional antenna designs. Distal end 112 of antenna 110 may be positioned opposite distal end 114, where antenna 110 conforms to a generally annular shape. Antenna 110 may form a single loop structure which extends around substantially all (e.g., more than 95% and, in some embodiments, more than 98%) of a periphery of region 130. For example, distal ends 112, 114 may be separated from one another to form therebetween a slit structure 120 extending to the exterior sidewall. As compared with an overall distance along the length of antenna 110 between distal ends 112, 114, a width w2 of slit structure 120 may be quite small—e.g., less than 4.0 mm (for example, in a range of 0.5 mm to 3.0 mm and, in some embodiments, between 0.75 mm and 1.5 mm).

Slit structure 120 may provide electrical insulation along a path extending directly between distal ends 112, 114. For example, slit structure 120 may have disposed therein any of a variety of a dielectric materials including, but not limited to a polycarbonate/acrylonitrile butadiene styrene (PC/ABS) material, a EXL1414 polycarbonate (PC) siloxane copolymer resin material and/or the like.

The region 130, circumscribed by the single-loop antenna 110, may have disposed therein logic (e.g., including the illustrative controller 140 shown) coupled to provide wireless communication using single-loop antenna 110. Logic of controller 140 may include any of a variety of combinations of hardware, firmware and/or executable software—e.g., where such logic comprises an application specific integrated circuit, field programmable circuitry, a process executing with a processor and/or the like. Controller 140 may be coupled—e.g., via interfaces 142, 144—to operate antenna 110. Interface 142 may comprise a conductor which is coupled to provide a short between controller 140 and a proximity-coupled feed structure 146 for driving communication with antenna 110. In such an embodiment, interface 144 may comprise a conductor which shorts controller 140 to antenna 110 via a contact which is at or near distal end 114. One or more spring contacts (not shown) may be used to couple interface 142 to feed structure 146 and/or to couple interface 144 to antenna 110.

As used herein with reference to the operation of a single loop antenna, “proximity-coupled feed structure” refers to a conductive structure that is positioned proximate to, but not in direct physical contact with, a side of an antenna. Communication using such a proximity-coupled feed structure may include an electromagnetic field interaction across a gap (or other intervening structure) which is between the proximity-coupled feed structure and the opposing side of the antenna. For example, transmit communication may include proximity-coupled feed structure 146 exciting electromagnetic radiation with antenna 110—e.g., wherein receive communication includes electromagnetic radiation at antenna 110 exciting a voltage signal or current signal from proximity-coupled feed structure 146 to controller 140 via interface 142.

Proximity-coupled feed structure 146 may include any of a variety of metals including, but not limited to, nickel, gold, copper, alloys (e.g., stainless steel) and/or the like. Proximity-coupled feed structure 146 may comprise a conductor

disposed proximate to a region of antenna 110 which is at or near a distal end thereof (e.g., proximate to distal end 112). Proximity-coupled feed structure 146 may be only indirectly coupled to distal end 112—e.g., via the in-series combination of interface 142, controller 140, interface 144 and the remaining portion of antenna 110 (which comprises distal end 114). In an embodiment, proximity-coupled feed structure 146 is electrically coupled to, and extends from, a printed circuit board which has controller 140 disposed therein or thereon. Proximity-coupled feed structure 146 may primarily extend along a direction which is substantially perpendicular to—e.g., \pm ten degrees (10°)—a top side of the printed circuit board. Alternatively or in addition, such a direction may be substantially parallel to—e.g., \pm ten degrees (10°)—interior side 118. Proximity-coupled feed structure 146 and interior side 118 may be separated from one another by an air gap or, in some embodiments, an insulator structure to provide a small offset therebetween.

In one illustrative embodiment, a separation distance between interior side 118 and a closest side of proximity-coupled feed structure 146 is in a range of 0.5 mm to 1.5 mm—e.g., wherein the spacing is in a range of 0.8 mm to 1.2 mm. Alternatively or in addition, a separation distance between proximity-coupled feed structure 146 and controller 140 (e.g., between proximity-coupled feed structure 146 and a PCB including controller 140) may be in a range of 0.5 mm to 5.0 mm. A sectional thickness of proximity-coupled feed structure 146 may be in a range of 0.05 mm to 0.2 mm, for example. Alternatively or in addition, a length of proximity-coupled feed structure 146 along a portion of interior side 118 may be in a range of 5.0 mm to 50.0 mm—e.g., in a range of 20 mm to 35 mm. This length may vary according to the overall length of antenna 110—e.g., to provide communication modes that each implement a respective one of a LTE lower band, LTE middle band and LTE upper band. The above-described dimensioning of proximity-coupled feed structure 146 and/or structures near proximity-coupled feed structure 146 is merely illustrative of some embodiments, and may vary according to implementation-specific details.

Although some embodiments are not limited in this regard, the dimensioning of proximity-coupled feed structure 146 may be achieved, for example, using laser direct structuring (LDS) processes—e.g., to define the formation of conductive structures onto a plastic film. After deposition of a conductor thereon, such a plastic film may be mounted into or on a metal frame or other support structure. In other embodiments, proximity-coupled feed structure 146 includes sheet metal, flexible printed circuit and/or the like.

Controller 140 may include any of various processor, controller and/or other circuit logic which, when executed, operates with proximity-coupled feed structure 146 and antenna 110 to perform signal transmission and/or signal reception. Such communication may, for example, be based on any of multiple communication modes of signaling which are capable of being performed with antenna 110. The multiple communication modes may, for example, include at least two different wavelength modes and, in some embodiments, at least three different wavelength modes. The different wavelength modes may, for example, include one or more of a one (1) wavelength mode, a two (2) wavelength mode and a three (3) wavelength mode. In this context, “N-wavelength mode” (for some positive integer N) refers to a mode of communication using an electromagnetic wave which has a given wavelength in an antenna, wherein an overall length of that antenna accommodates N times that wavelength—e.g., but not N+1 times that wavelength. In

one illustrative embodiment, the one-wavelength mode may provide a LTE low band including a range of 800 MHz to 960 MHz (e.g., for any of LTE bands B5 and B8)—e.g., wherein the two-wavelength mode provides a LTE mid-band including a range from 1710 MHz to 2200 MHz (e.g., for any of LTE bands LTE B1, B2, B3 and B4) and/or the three-wavelength mode provides a LTE high band including a range from 2300 MHz to 2700 MHz (e.g., for any of LTE bands B38, B39, B41 and B7). However, more, fewer and/or different modes and/or frequency bands may be provided by operation of antenna **110**, in other embodiments.

Antennas tend to radiate when an imaginary part of their input impedance is at or near zero. For a loop antenna, reduction of the imaginary part of its impedance may be facilitated when the antenna's length (e.g., circumferential distance) is at or near one wavelength, or an integer multiple of one wavelength. In some embodiments, a wavelength mode may be facilitated by a dimensioning of antenna **110** which accounts for the proximity of a user's body tissue to device **100**. By way of illustration and not limitation, a communication in a LTE low communication band may, for example, have a frequency of 850 MHz which corresponds to a wavelength of approximately 350 mm in air or in a vacuum. However, the 850 MHz communication may be provided during a one-wavelength mode of antenna **110**, wherein the overall length of antenna **110**—as measured around a periphery of region **130** between distal ends **112**, **114**—is substantially smaller (e.g., at least 10% more) than 350 mm. In one example embodiment, the overall length of antenna **110** is in a range of 185 mm to 195 mm (e.g., where $w1$ is between 55 mm and 65 mm). This significantly smaller overall length of antenna **110** may account for load effects that may be due to the proximity of a user's body tissue.

Although some embodiments are not limited in this regard, controller **140** (and/or other circuitry in region **130**) may provide communication device **100** with other functionality in addition to that for communication using antenna **110**. For example, region **130** may have disposed therein processor, memory and/or other circuit logic to execute an operating system and/or other software processes. Alternatively or in addition, circuitry of communication device may provide input/output functionality (e.g., with display, audio, haptic, touchscreen and/or other mechanisms of communication device **100**) for providing a user with access to such an operating system. Other circuitry of communication device **100** may provide sensor functionality (e.g., temperature, vibration, pressure, motion, etc.) and/or alternative types of communication (e.g., near field communication), although some embodiments are not limited in this regard.

FIG. 1B illustrates features of a body mountable communication device **150** to provide high-frequency (e.g., LTE) communication according to another embodiment. Communication device **150** may include one or more features of communication device **100**—e.g., wherein a cross-sectional profile of communication device **150** conforms to a rectangular shape, rather than a circle. In the illustrative embodiment shown, communication device **150** includes a single-loop antenna **160**, slit structure **170**, controller **190** and proximity-coupled feed structure **196** which, for example, provide corresponding functionality of single-loop antenna **110**, slit structure **120**, controller **140** and proximity-coupled feed structure **146**, respectively. Antenna **110** may have a height $h2$, width $w3$ and sectional thickness $t2$ (e.g., having respective features of height $h1$, width $w1$ and sectional thickness $t1$).

As variously shown in the side view **151** and top view **152** of communication device **150**, an exterior side **166** of

antenna **160** (the side **166** opposite an interior side **168**) may form at least in part an exterior sidewall structure of communication device **150**. Distal ends **162**, **164** of antenna **110** may be positioned on opposite respective sides of slit structure **170**, where antenna **160** conforms to a generally annular rectangle shape. The region **180** circumscribed by antenna **160** may have disposed therein controller **190** coupled to provide wireless communication using single-loop antenna **160**. For example, controller **190** may be coupled via interfaces **192**, **194** to operate antenna **160**. Interfaces **192**, **194** may, for example, correspond to interfaces **142**, **144**, respectively. Controller **190** may facilitate any of two or more modes that each implement a respective one of multiple radio frequency communication bands—e.g., including two or more of a LTE lower band, LTE middle band and LTE upper band.

FIG. 2 illustrates elements of a method **200** to operate a body-mountable device. Method **200** may be performed at one of body-mountable communication devices **100**, **150** or any of various other body-mountable devices having features described herein.

In one embodiment, method **200** comprises, at **210**, receiving a signal indicating that communication with a single-loop antenna of the body-mountable device is to take place in a first frequency band. The first frequency band may be a high-frequency band—e.g., wherein each frequency in the first frequency band is above 100 MHz. The signal received at **210** may include or otherwise be based on any of a variety of one or more inputs provided to circuitry of the body-mountable device—e.g., wherein the single-loop antenna extends around a region including such circuitry. Such an input may be provided, for example, by a manufacturer, distributor, retailer, administrator, user, or other agent. An input may be provided by direct interaction with a touchscreen, microphone, haptic sensor and/or other input mechanism of the body-mountable device. Alternatively or in addition, an input may be received via with the single-loop antenna or via another wireless communication component of the body-mountable device. In one example embodiment, the signal received at **210** may be based at least in part upon a passive detection of a communication functionality which is supported by a wireless network in a region accessible to the body-mountable device. However, some embodiments are not limited with respect to the particular source and/or form of the received signal.

In an embodiment, the single-loop antenna has features of one of antennas **110**, **160**. For example, an exterior sidewall of the body-mountable device may be formed at least in part by the single-loop antenna, where distal ends of the single-loop antenna are disposed on opposite respective sides of a slit structure in the exterior sidewall. An overall length of the single-loop antenna—e.g., as measured along the single-loop antenna from one of the distal ends to the other of the distal ends—may be equal to or less than 250 mm.

Method **200** may further comprise, at **220**, selecting, based on the signal, a first operational mode from among a plurality of operational modes which are each to provide, with both a proximity-coupled feed structure and a first contact at the single-loop antenna, a respective wavelength mode of communication by the single-loop antenna. For example, the first operational mode may correspond to a first frequency band above 100 MHz, wherein the first operational mode provides a first wavelength mode of communication (e.g., a one-wavelength mode) by the single-loop antenna. By contrast, a second operational mode of the plurality of operational modes may correspond to a second frequency band which is also above 100 MHz, the second

operational mode to provide a second wavelength mode of communication by the single-loop antenna, the second wavelength mode (e.g., a two-wavelength mode) different than the first wavelength mode.

In such an embodiment, two or more of the plurality of operational modes—e.g., including at least the first operational mode and the second operational mode—is to provide a respective operation of the single-loop antenna using both the proximity-coupled feed structure and the first contact (e.g., with both proximity-coupled feed structure 146 and a contact where interface 144 couples to antenna 110). For example, three or more of the plurality of operational modes may each provide a different wavelength mode of the single-loop antenna using the proximity-coupled feed structure and the first contact.

The first operational mode may provide communication with the single-loop antenna at a first frequency—e.g., wherein the second operational mode is to provide communication with the single-loop antenna at a second frequency, and wherein a difference between the first frequency and the second frequency is at least 1000 megahertz (MHz). For example, the difference between the first frequency and the second frequency may be at least 1500 MHz (and in some embodiments, at least 2000 MHz). Alternatively or in addition, two or more of the plurality of operational modes may each provide communication with the single-loop antenna in a respective band defined, for example, by a Long-Term Evolution (LTE) standard. For example, the plurality of operational modes may include operational modes each to provide a different respective one of a one-wavelength mode of communication in a LTE low band, a two-wavelength mode of communication in a LTE mid-band and a three-wavelength mode of communication in a LTE high band.

In an embodiment, method 200 comprises configuring the first operational mode, at 230, based on the selecting at 220. The configuring at 230 may, for example, include setting a configuration of a receiver circuit coupled to the single-loop antenna and/or a transmitter circuit coupled to the single-loop antenna. Subsequently, at 240, method 200 perform a wireless communication with a first wavelength mode of the single-loop antenna.

In some embodiments, method 200 includes additional operations (not shown) to transition the body-mountable device from an operational mode corresponding to one high-frequency band to another operational mode corresponding to a different high-frequency band. For example, method 200 may further comprise receiving another signal (e.g., similar to that received at 210) indicating that communication with the single-loop antenna is to take place in a different frequency band above 100 MHz. Based on this other signal, method 200 may further select another operational mode (e.g., the second operational mode) from among the plurality of operational modes. This other selected operational mode may be subsequently configured and used for performing additional wireless communication with the single-loop antenna.

FIG. 3 illustrates features of a body mountable communication device 300 to provide wireless LTE communication according to another embodiment. Communication device 300 may include features of one of communication devices 100, 150, for example. In the illustrative embodiment shown, communication device 300 includes a single-loop antenna 310, slit structure 320, printed circuit board (PCB) 330 and proximity-coupled feed structure 350 which, for example, provide corresponding functionality of single-loop antenna 110, slit structure 120, controller 140 and proximity-coupled feed structure 146, respectively.

As variously shown in the exterior side view 301 and cutaway side view 302 of communication device 300, an exterior side of antenna 310 may form at least in part an exterior sidewall structure of communication device 300. Distal ends of antenna 310 may be positioned on opposite respective sides of slit structure 370 for antenna 310 to conform to a generally annular rectangle shape. The region circumscribed by antenna 310 may have disposed therein circuitry (e.g., disposed in or on PCB 330) coupled to provide wireless communication using single-loop antenna 310. For example, PCB 330 may be electrically shorted both to one end of antenna 310 and to proximity-coupled feed structure 350, wherein an opposite end of antenna 310 is proximate to—but not directly in contact with—proximity-coupled feed structure 350.

In one illustrative embodiment, a distance between antenna 310 and proximity-coupled feed structure 350 is in a range of 0.5 mm to 1.5 mm—e.g., wherein a distance dB between proximity-coupled feed structure 350 and PCB 330 is in a range of 0.5 mm to 5.0 mm. A battery 332, disposed in a housing structure 340 of communication device 300, may be coupled to provide power for high frequency wireless communication by PCB 330 and antenna 310. Battery 332 may further provide power for operation of one or more I/O components such as the illustrative display panel 334 which is disposed under a display glass 336.

FIG. 4 illustrates features of a system 400 including a body mountable communication device 402 to provide wireless LTE communication according to another embodiment. System 400 may function as a smartwatch, smart badge or other wearable communication device—e.g., wherein wrist-band 404a, 404b facilitate fastening of communication device 402 around a wrist of a user.

Communication device 402 may include features of one of communication devices 100, 150, 300, for example. Single-loop antenna 410 may form a sidewall structure of communication device 402, wherein distal ends of antenna 410 are disposed on opposite sides of a slit structure 420. Single-loop antenna 410 may extend around substantially all of a region in which is disposed a printed circuit board 430, battery 432, display panel 434, display glass 436, housing structure 440 and proximity-coupled feed structure 450—e.g., which provide the corresponding functionality of printed circuit board 330, battery 332, display panel 334, display glass 336, housing structure 340 and proximity-coupled feed structure 350, respectively.

Circuitry disposed in or on PCB 430 may be coupled to antenna 410 and proximity-coupled feed structure 450—e.g., where such circuitry is configured to participate in LTE (or other) communications using antenna 410 and proximity-coupled feed structure 450. Such communication may include any of a plurality of available communication modes that, for example, include various wavelength modes.

FIG. 5 illustrates features of a body mountable communication device 500 to provide wireless LTE communication according to another embodiment. Communication device 500 may include features of one of communication devices 100, 150, 300, 402, for example. Communication device 500 may include a single-loop antenna 510 extending around a region 530 in which or under which is disposed a housing structure 540 (e.g., where a display glass forms a top of region 530). Antenna 510 may form an exterior sidewall structure of communication device 500. Distal ends of antenna 510 may variously form opposite sides of a slit structure 520. In an embodiment, antenna 510, housing

structure **540** and slit structure **520** correspond functionally to antenna **410**, housing structure **440** and slit structure **420**, respectively.

Communication device **500** is one example of an embodiment wherein an antenna has formed therein a hole and/or a recess structure to facilitate space-efficient placement and operation of a sensor or input/output mechanism. By way of illustration and not limitation, a first hole extending through antenna **510** may be aligned to receive a button **512** operable by a user to navigate among elements of a graphical user interface (GUI) or otherwise operate circuit logic and/or executing software logic of communication device **500**. Alternatively or in addition, a second hole **514** may extend through antenna **510**, the second hole **514** aligned to enable a communication of sound from a speaker of communication device **500** and/or a receipt of sound at an acoustic sensor (e.g., a microphone) of communication device **500**. However, the number, type and/or location of one or more I/O mechanisms that may be accommodated each a respective hole formed in antenna **510** may vary in different embodiments.

FIG. **5** further illustrates features of a body mountable communication device **550** to provide wireless LTE communication according to another embodiment. Communication device **550** may include features of one of communication devices **100**, **150**, **300**, **402**, for example. Communication device **550** may include a single-loop antenna **560** extending around a region **580** in which is disposed a housing structure **590**. Antenna **560** may form an exterior sidewall structure of communication device **550**. Distal ends of antenna **560** may variously form opposite sides of a slit structure **570**. In an embodiment, antenna **560**, housing structure **590** and slit structure **570** correspond functionally to antenna **510**, housing structure **540** and slit structure **520**, respectively.

Communication device **550** is another example of an embodiment wherein an antenna has formed therein one or more recess structures each to facilitate space-efficient placement and operation of a respective input/output mechanism. By way of illustration and not limitation, a recess structure extending into a top side of antenna **560** may be aligned with an I/O mechanism **582** of communication device **550**—e.g., wherein I/O mechanism **582** includes a speaker, microphone, infrared sensor and/or the like. The number, type and/or location of one or more I/O mechanisms that may be accommodated each a respective recess structure formed in antenna **560** may vary in different embodiments.

In some embodiments, any hole or recess structure that extends through an antenna (e.g., through one of antennas **510**, **560**) is at least some minimum distance away from the slit structure formed between distal ends of the antenna. For example, any such hole or recess structure may be offset from the slit structure by at least ten percent (10%) of the overall distance along the interior side of the antenna. This offsetting of any such hole or recess structure may mitigate the possibility of a user shorting the distal ends of the antenna while touching a hole or recess structure formed in the antenna.

FIG. **6** is a block diagram illustrating further details of one example of a communication device **600** according to an embodiment. Communication device **600** may include features of one of devices **100**, **150**, **300**, **402**, **500**, for example. In an embodiment, communication device **600** includes one or more components to perform operations of method **200**.

As shown in the example of FIG. **6**, communication device **600** includes an antenna **610**, one or more processors

640, memory **642**, network interface **648**, storage device **650**, one or more input devices **652**, one or more output devices **654**, power source **656**, one or more accelerometers **658** and selector logic **630**. Communication device **600** may also include an operating system **644** and one or more applications **646**—e.g., some or all of which execute with one or more processors **640**. Each of components **610**, **630**, **640**, **642**, **644**, **646**, **648**, **650**, **652**, **654**, **656** and **658** may be interconnected (physically, communicatively, and/or operatively) for inter-component communications.

One or more processors **640** may be configured to implement functionality or process instructions for execution in communication device **600**. Processors **640** may be capable of processing instructions stored in memory **642** or instructions stored on storage device **650**.

Memory **642** may be configured to store information within communication device **600** during operation. Memory **642** may, in some examples, be described as a non-transitory or tangible computer-readable storage medium. In some examples, memory **642** is a temporary memory, meaning that a primary purpose of memory **642** is not long-term storage. Memory **642** may also, in some examples, be described as a volatile memory, meaning that memory **642** does not maintain stored contents when communication device **600** is turned off. Examples of volatile memories include random access memories (RAM), dynamic random access memories (DRAM), static random access memories (SRAM), and other forms of volatile memories known in the art. In some examples, memory **642** may be used to store program instructions for execution by one or more processors **640**. Memory **642** may be used by software or applications running on communication device **600** (for example, one or more of applications **646**) to temporarily store information during program execution.

Storage device **650** may also include one or more non-transitory or tangible computer-readable storage media. Storage device **650** may be configured for long-term storage of information. In some examples, storage device **650** may include non-volatile storage elements. Examples of such non-volatile storage elements may include optical discs, flash memories, or forms of electrically programmable memories (EPROM) or electrically erasable and programmable (EEPROM) memories.

Communication device **600** may also include one or more input devices **652**. Input devices **652** may be configured to receive input, for example, from a user, through tactile, audio, or video input. Examples of input devices **652** may include a touch-sensitive display, a voice responsive system, a microphone, a camera, or any other type of device for detecting a command or input from a user. In some examples, one or more input devices **652** may also be an output device **654**.

One or more output devices **654** may also be included in communication device **600**, for example, a speaker. Output devices **654** may be configured to provide output to a user using tactile, audio, or video output. Output devices **654** may utilize a speaker, a graphics processor, or any other type of device for converting a signal into an appropriate form understandable to humans or machines. Additional examples of output devices **654** may include a liquid crystal display (LCD) or any other type of device that can provide output to a user. An output device **654** may also be a touch-sensitive or presence-sensitive screen. In one example, one or more output devices **654** may also be an input device **652**.

Communication device **600** may include power source **656**, which may be rechargeable and provide power to communication device **600**. The power source **656** may be

one or more batteries. The one or more batteries may be made from nickel-cadmium, lithium-ion, or any other suitable material. In another example, the power source **656** may include a power supply connection that receives power from a power source external to communication device **600**.

Communication device **600** may utilize network interface **648** to communicate via antenna **610** with external devices via one or more networks (for example, a cellular or other network which supports LTE communication). Selector logic **630**—e.g., comprising one or more of circuit hardware, firmware and executable software—may operate to select a particular one of multiple possible operational modes (such as the illustrative modes OMI, . . . , OMn shown), two or more of which are to provide a different respective wavelength mode of communication using antenna **610**. Selector logic **630** and network **648** may, for example, provide functionality of one of controllers **140**, **190**—e.g., wherein antenna **610** is a functional representation of one of antennas **110**, **160**. In such an embodiment, selector logic **630** may perform operations of method **200** to implement one of modes OMI, . . . , OMn.

In one example, network interface **648** may correspond to wireless interface for receiving data from a remote device. In some examples, communication device **600** may include a plurality of either or both input and output interfaces. In some examples, network interface **648** may include separate input and output network interfaces. In other examples, input and output interfaces may be may be functionally integrated.

Network interface **648** may include a transceiver circuitry and, in some embodiments, circuitry to implement Ethernet, transmission control protocol (TCP), Internet protocol (IP), asynchronous transfer mode (ATM), or other network communication protocols. In other examples, network interface **648** may be a transceiver operable to send and receive information in any of multiple high-frequency bands (e.g., two or more of which correspond to different respective wavelength modes of antenna **610**). Examples of such network interfaces may include 4G, LTE Advanced, Bluetooth®, 3G and WiFi® radios in mobile computing devices as well as USB. In some examples, communication device **600** may utilize network interface **648** to wirelessly communicate with an external device, such as another body-mountable device, a server, or other networked computing device.

Communication device **600** may include operating system **644**. Operating system **644** may control the operation of components of communication device **600**. For example, operating system **644** may facilitate the interaction of application **646** with processors **640**, memory **642**, network interface **648**, storage device **650**, input devices **652**, output devices **654** and power source **656**.

Any applications, for example applications **646**, implemented within or executed by communication device **600** may be implemented or contained within, operable by, executed by, or be operatively or communicatively coupled to components of communication device **600**, for example, one or more processors **640**, memory **642**, network interface **648** or storage device **650**.

Techniques described herein may be implemented, at least in part, in hardware, software, firmware, or any combination thereof. For example, various aspects of the described embodiments may be implemented within one or more processors, including one or more microprocessors, digital signal processors (DSPs), application specific integrated circuits (ASICs), field programmable gate arrays (FPGAs), or any other equivalent integrated or discrete logic circuitry,

as well as any combinations of such components. The term “processor” or “processing circuitry” may generally refer to any of the foregoing logic circuitry, alone or in combination with other logic circuitry, or any other equivalent circuitry. A control unit including hardware may also perform one or more of the techniques of this disclosure.

Such hardware, software, and firmware may be implemented within the same device or within separate devices to support the various techniques described herein. In addition, any of the described units, modules or components may be implemented together or separately as discrete but interoperable logic devices. Depiction of different features as modules or units is intended to highlight different functional aspects and does not necessarily imply that such modules or units are realized by separate hardware, firmware, or software components. Rather, functionality associated with one or more modules or units may be performed by separate hardware, firmware, or software components, or integrated within common or separate hardware, firmware, or software components.

Techniques described herein may also be embodied or encoded in an article of manufacture including a computer-readable storage medium encoded with instructions. Instructions embedded or encoded in an article of manufacture including an encoded computer-readable storage medium, may cause one or more programmable processors, or other processors, to implement one or more of the techniques described herein, such as when instructions included or encoded in the computer-readable storage medium are executed by the one or more processors. Computer readable storage media may include random access memory (RAM), read only memory (ROM), programmable read only memory (PROM), erasable programmable read only memory (EPROM), electronically erasable programmable read only memory (EEPROM), flash memory, a hard disk, a compact disc ROM (CD-ROM), a floppy disk, a cassette, magnetic media, optical media, or other computer readable media. In some examples, an article of manufacture may comprise one or more computer-readable storage media.

In some examples, computer-readable storage media may comprise non-transitory media. The term “non-transitory” may indicate that the storage medium is not embodied in a carrier wave or a propagated signal. In certain examples, a non-transitory storage medium may store data that can, over time, change (for example, in RAM or cache).

Various aspects of the disclosure have been described. Aspects or features of examples described herein may be combined with any other aspect or feature described in another example. These and other embodiments are within the scope of the following claims.

What is claimed is:

1. A body-mountable device comprising:
 - an antenna substantially circumscribing a region of the body-mountable device, the antenna composed of a conductive material and having a first distal end and a second distal end separated by an insulative slit structure extending between an interior surface and an opposing exterior surface of the antenna, the exterior surface of the antenna and the insulative slit structure together forming an exterior sidewall of the body-mountable device and the interior surface of the antenna and the insulative slit structure together circumscribing a region of the body-mountable device;
 - a proximity-coupled feed structure disposed at the region and separated from the antenna by a gap; and

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- a controller disposed at the region and coupled to the antenna via a first conductor and coupled to the proximity-coupled feed structure via a second conductor.
- 2. The body-mountable device of claim 1, wherein the controller is configured to conduct wireless signaling via the antenna and proximity-coupled feed structure.
- 3. The body-mountable device of claim 2, wherein the controller is configurable to operate in a select one of a plurality of available operational modes, including:
 - a first operational mode corresponding to a first frequency band above 100 megahertz (MHz), the first operational mode to provide a first wavelength mode of communication by the antenna; and
 - a second operational mode corresponding to a second frequency band above 100 MHz, the second operational mode to a second wavelength mode of communication by the antenna, the second wavelength mode different than the first wavelength mode.
- 4. The body-mountable device of claim 2, further comprising:
 - a printed circuit board disposed at the region, wherein the controller is implemented at the printed circuit board.
- 5. The body-mountable device of claim 1, further comprising:
 - a display panel disposed at the region; and display glass overlying the display panel.
- 6. The body-mountable device of claim 5, further comprising:
 - an aperture extending between the interior surface and the exterior surface of the antenna; and
 - a user-manipulatable button disposed at least partially in the aperture and coupled to the controller, the button configured to receive user input to facilitate navigation of a graphical user interface (GUI) displayed by the controller via the display panel.
- 7. The body-mountable device of claim 1, further comprising:
 - a battery disposed at the region and configured to provide power to the controller.
- 8. The body-mountable device of claim 1, further comprising:
 - an aperture extending between the interior surface and the exterior surface of the antenna; and
 - a sensor disposed at the region and aligned with the aperture.
- 9. The body-mountable device of claim 1, wherein the first conductor is in physical and electrical contact with the antenna via at least one spring contact.
- 10. The body-mountable device of claim 1, wherein the insulative slit structure is composed of a dielectric material.
- 11. The body-mountable device of claim 1, wherein the region is substantially cylindrical.
- 12. The body-mountable device of claim 1, wherein the region is substantially cuboid.
- 13. The body-mountable device of claim 1, wherein a length of the interior surface of the antenna between the first distal end and the second distal end is at least 95% of a

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- length of a periphery of the region circumscribed by the interior surface of the antenna and the insulative slit structure.
- 14. The body-mountable device of claim 13, wherein a width of the insulative slit structure between the first distal end and the second distal end of the antenna is not greater than 4 millimeters.
- 15. A smartwatch comprising:
 - first and second watchbands; and
 - a communication device having a watch form factor and coupled to the first and second watchbands, the communication device including:
 - an antenna substantially circumscribing a region, the antenna having two distal ends separated by a non-conductive gap, the non-conductive gap defining a portion of a periphery of the region, and wherein the antenna and the non-conductive gap together form an exterior sidewall of the communication device;
 - a controller disposed in the region, the controller configured to conduct wireless signaling via the antenna using a feed structure adjacent to the antenna;
 - a display panel disposed in the region and coupled to the controller, the display panel configured to display a graphical user interface (GUI); and
 - a button coupled to the controller and disposed at least partially in a first aperture extending between an interior surface and an opposing exterior surface of the antenna, the button configured to be manipulated by a user to facilitate navigation of the GUI.
- 16. The smartwatch of claim 15, further comprising:
 - a sensor disposed in the region and coupled to the controller, the sensor aligned with a second aperture that extends between the interior surface and the exterior surface of the antenna.
- 17. The smartwatch of claim 16, wherein the sensor comprises a microphone.
- 18. The smartwatch of claim 15, wherein the controller is configurable to operate in a select one of a plurality of available operational modes, including:
 - a first operational mode corresponding to a first frequency band above 100 megahertz (MHz), the first operational mode to provide a first wavelength mode of communication by the antenna; and
 - a second operational mode corresponding to a second frequency band above 100 MHz, the second operational mode to a second wavelength mode of communication by the antenna, the second wavelength mode different than the first wavelength mode.
- 19. The smartwatch of claim 15, wherein the non-conductive gap is filled with a dielectric material.
- 20. The smartwatch of claim 15, wherein the watch form factor has one of a circular watch face or a rectangular watch face.

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